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OPTIMIZE THE EFFECT OF FRICTION STIR PROCESS ON NATURAL FREQUENCY OF AA6061 ALLOYS BY USING FUZZY LOGIC CONTROL SYSTEM

MAHA M. A. LASHIN[1,2] & FADWA ALROWAIS[3]

[1]*College of Engineering, Princess Nourah bint Abdulrahman University, Riyadh, Kingdom of Saudi Arabia*

[2]*Department of Mechanical Engineering, Faculty of Engineering Shoubra, Banha University, Egypt*

[3]*Computer Sciences Department in College of Computer and Information Sciences, Princess Nourah bint Abdulrahman University, Riyadh, Kingdom of Saudi Arabia*

ABSTRACT

A Fuzzy logic control system is implemented to optimize the natural frequencies and damping for some AA6061 aluminum products. These products are manufactured using friction stir welding. Due to the wide use of these products in several dynamic applications, an experimental investigation of the spectral analysis is used to apply Fuzzy control. This investigation was implemented for several friction stir welding conditions. The application of the developed fuzzy system indicates that natural frequency and damping ratio increase in rotating and traversal speeds at the same values of tool angle and depth of cut. In the present work, the value of natural frequency for AA6061 aluminum alloy plate welded by friction stir was optimized by fuzzy logic control system. Section 2 describes the AA6061 aluminum plate specification. Section 3 explains the methodology which depends on fuzzy system that is defined in section 4. The final section summarizes the results and conclusions drawn from this work.

KEYWORDS: AA6061 Aluminum Alloy, Friction Stir Welding, Natural Frequency, Fuzzy System & Rotational and Travers Speeds

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Original Article

INTRODUCTION

Natural frequency of any material is an important property, which should be considered while using it at any application for avoiding the possibility of resonance (Durga prasad et al., 2015). Material mass and stiffness (Young's modulus and arrangement of constraints) influence its natural frequency.

AA6061 aluminum alloys consist of magnesium and silicon to produce a precipitation-hardened aluminum (Sanders,2001). It is the most common alloys of aluminum for general-purpose use. The role of aluminum alloys in industrial applications is based on its properties like light weight, lower corrosion rate and natural frequency. They play a very important role in using these alloys in different applications. The mechanical properties of AA6061 aluminum alloy mainly depend on the heat treatment of the material. Its Young's Modulus is 69 GPa regardless of temper (ASM, 1991).

Natural frequencies of aluminum change between (1744.4 – 6356.6) Hz are based on eigen value and eigenvector mathematical method (Klimenda, and Soukup, 2017). The natural frequencies for AA6061 aluminum alloys decrease with the use of tire rubber for covering the tested plats as an insulated (Ramu, and Reddy, 2007). The corresponding natural frequencies of the welding AA6061 aluminum alloys samples has increased slightly with

respect to the defect-free weld, e.g. the natural frequency of the defective joint has no significant effect on the detection of internal defects, especially if these defects are small (AbuShanab, and Moustafa, 2018).

Friction Stir Welding (FSW) is a special type of welding named solid-state joining process which combines deformation heating and mechanical work to obtain high quality without defect joints. FSW is suited for joining Aluminum Alloys in a large range of plate thickness and long lengths with excellent quality (Muzammil, 2017). The mechanical properties and microstructure of aluminum alloy AA6061 change with alterations in values of welding and tool rotational speeds. The best values of tensile strength and joint efficiency appeared at (10-40 mm/min) welding speed and 900 r.p.m rotating speed (Mahmood, 2013).

Tool feed rate and axial force also influence the mechanical properties of AA6061 aluminum alloys (Wang et al., 2012; Hema, 2019).

Fuzzy logic control system offers a formalized format for creating a high-resolution, clear, and easy-to-interpret numerical system. A need of creating fuzzy model (fuzzy system) is to know the system purpose for determining inputs required (input set) to achieve the desired outputs (output set) through fuzzy rules (If-than rule) (Sharma, 2011).

Ramalingam and Ramasamy (2017) applied Mamdani fuzzy system to generate a model for predicting and exploring the influence of friction stir welding process parameters on tensile strength of AA1100 aluminum alloy joints. The results of this work proved that the developed predictive fuzzy system model can predict tensile stress of the friction stir welding for aluminum alloy AA1100.

Optimization of parameters was done through fuzzy algorithm for obtaining minimum wear and frictional force (Kumar and Ramanujam, 2015). Analysis of results revealed that an increase in wear resistance is related to the increase of reinforced particle. Further, the responses of wear parameter have improved by fuzzy control system analysis.

Vijayanand Rao (2017) used fuzzy system to study effect of fraction stir welding parameters (namely rotational speed (N), welding speed (F), axial load (P) and pin shape (PS)) on the material characteristics. The results have shown improving tensile properties of AA6061 aluminum alloy related to optimization of these parameters by using fuzzy logic control system.

PLATE SPECIFICATIONS

The AA6061 aluminum alloy plate that is being studied contains magnesium and silicon, as it's in the major of alloying elements, with dimensions of 6000 mm (length) × 70 mm (width) × 10mm (thickness). The plate was fabricated related to friction stir process in a single pass using a steel tool with rotating speed at 500, 800 and 1000 rpm and traverse speeds 5, 10 and 15 mm/min. The tool angle was 1^{o}, 3^{o}, and 6^{o} for cutting depth 4, 9, and 14 mm.

FUZZY LOGIC CONTROL SYSTEM

Fuzzy modelling techniques allow generating fuzzy models considering precision and interpretability fuzzy system via multi-objective optimisation techniques (Coello and Becerra, 2009). Fuzzy systems are considered as universal approximators, capable of performing nonlinear relations of inputs and outputs (Zhang et al., 2011).

Fuzzy system works through three steps; first one is the classification step (fuzzification-inputs), second is the definition of fuzzy decision or knowledge base (fuzzy rules) that fine the activity values for each rule output through inference

engine, and third step is the defuzzfication which generates values for output variables of fuzzy system, as shown in Figure 1.

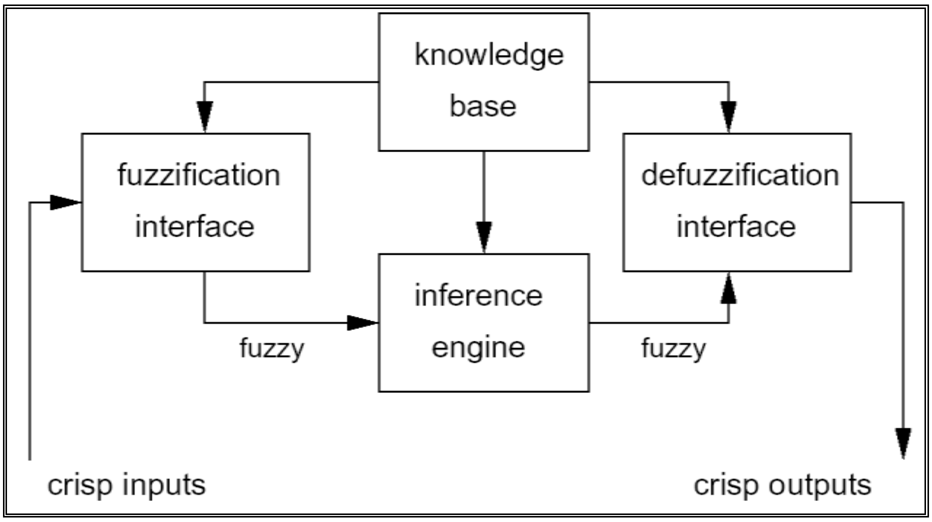

Figure 1: Fuzzy System Process.

In the present work, two fuzzy systems for optimizing natural frequency and damping ratio of AA6061 aluminim alloy were designed and structured by rotational and travers welding speed, where tool angle and depth of cut as inputs were as described in section 2.

Classification (Fuzzification)

This step starts by converting the inputs of fuzzy system to sets of fuzzy variables by giving labeled membership function values for each set as shown in Figure 2. Both natural frequency and damping ratio fuzzy systems have four inputs with three levels low, medium, and high as shown in Table 1.

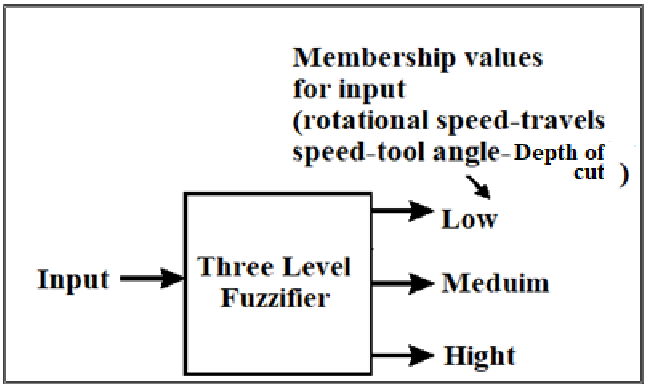

Figure 2: Fuzzification Step.

Table 1: Levels of Fuzzy Systems Inputs Value

Input Variables	Three Levels		
	Low	Medium	High
Rotational Speed	500 r.p.m	800 r.p.m	1000 r.p.m
Travers Speed	5 mm/min	10 mm/min	15 mm/min
Tool Angle	1^o	3^o	6^o
Depth of Cut	4 mm	9 mm	14 mm

Fuzzy Decision Block

In this step, fuzzy equivalents AND, OR and NOT operation statements are used for constructing the fuzzy rules which are known by IF-THAN rules as a part of the proposed fuzzy control or fuzzy optimization process. Table 2 shows some of the fuzzy rules that were implemented in natural frequency and damping ration fuzzy systems.

Table 2: Some of Natural Frequency and Damping Ration Fuzzy Systems Rules

Fuzzy Rules (IF-THAN Rules) – Relationship Between Inputs and Output
If (Rotational-Speed-(r.p.m) is Low) and (Travers-Speed-(mm/min) is Medium) and (Tool-Angle-(o) is Medium) and (Depth-of-cut-(mm) is Medium) then (Natural-Frequency is Medium) (1)
If (Rotational-Speed-(r.p.m) is Medium) and (Travers-Speed-(mm/min) is Low) and (Tool-Angle-(o) is Medium) and (Depth-of-cut-(mm) is Medium) then (Natural-Frequency is Low) (1)
If (Rotational-Speed-(r.p.m) is Medium) and (Travers-Speed-(mm/min) is High) and (Tool-Angle-(o) is Medium) and (Depth-of-cut-(mm) is Medium) then (Natural-Frequency is Low) (1)
If (Rotational-Speed-(r.p.m) is High) and (Travers-Speed-(mm/min) is Medium) and (Tool-Angle-(o) is Medium) and (Depth-of-cut-(mm) is Medium) then (Natural-Frequency is High) (1)
If (Rotational-Speed-(r.p.m) is Medium) and (Travers-Speed-(mm/min) is High) and (Tool-Angle-(o) is Medium) and (Depth-of-cut-(mm) is Medium) then (Damping_-Ratio is Medium) (1)
If (Rotational-Speed-(r.p.m) is Medium) and (Travers-Speed-(mm/min) is Medium) and (Tool-Angle-(o) is Medium) and (Depth-of-cut-(mm) is Medium) then (Damping_-Ratio is Medium) (1)
If (Rotational-Speed-(r.p.m) is High) and (Travers-Speed-(mm/min) is Low) and (Tool-Angle-(o) is Medium) and (Depth-of-cut-(mm) is Medium) then (Damping_-Ratio is Medium) (1)
If (Rotational-Speed-(r.p.m) is High) and (Travers-Speed-(mm/min) is High) and (Tool-Angle-(o) is Medium) and (Depth-of-cut-(mm) is Medium) then (Damping_-Ratio is Low) (1)

Defuzzification

This step is done by combining the fuzzy variables (fuzzy system inputs) into a real signals (values) for determining of the optimum values for natural frequency and damping ratio, as shown in Figure 3.

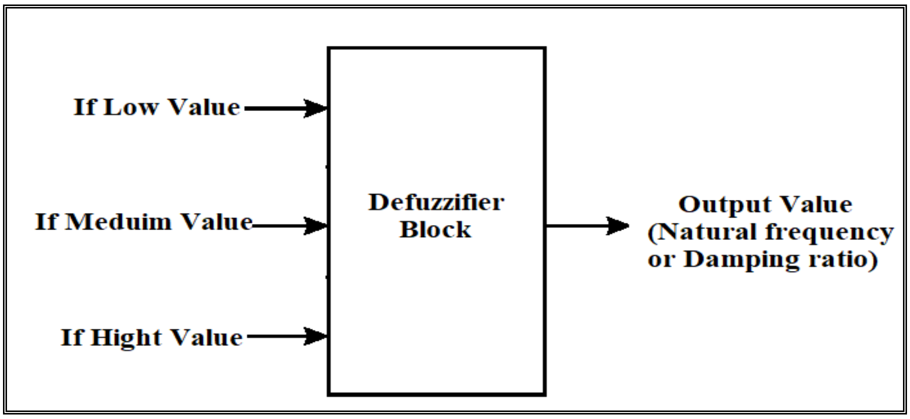

Figure 3: Defuzzifcation Step.

NATURAL FREQUENCY FUZZY SYSTEM

A fuzzy system with four inputs (Rotational speed, Travers speed, tool angle, and depth of cut) was designed based on MATLAB software to optimize the natural frequency for AA6061 aluminum alloy structure, as shown in Figure 4. The low, medium, and high values for inputs and outputs are explained in Figure 5. If-THAN rules that were used to establish relationships between inputs and outputs are shown in Figure 6. This is done in order to achieve the minimum and maximum of natural frequency, as shown in Figure 7 and Table 3.

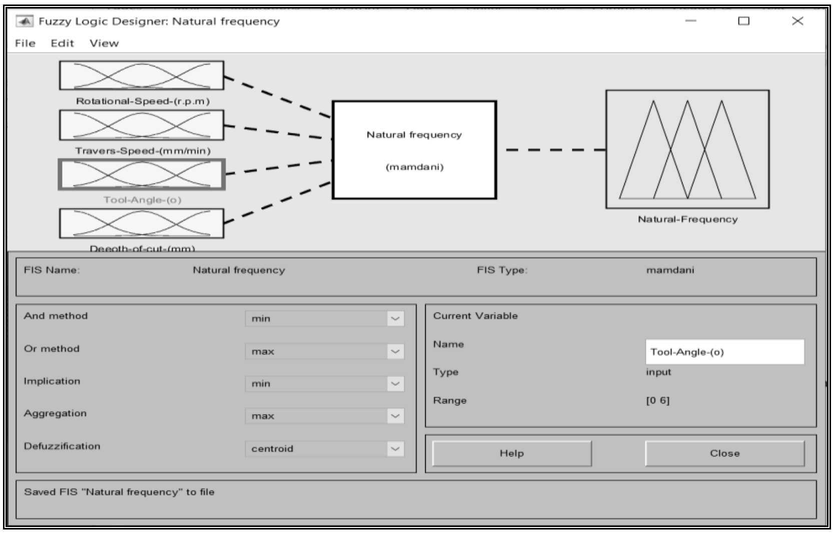

Figure 4: Natural Frequency Fuzzy Control Logic System.

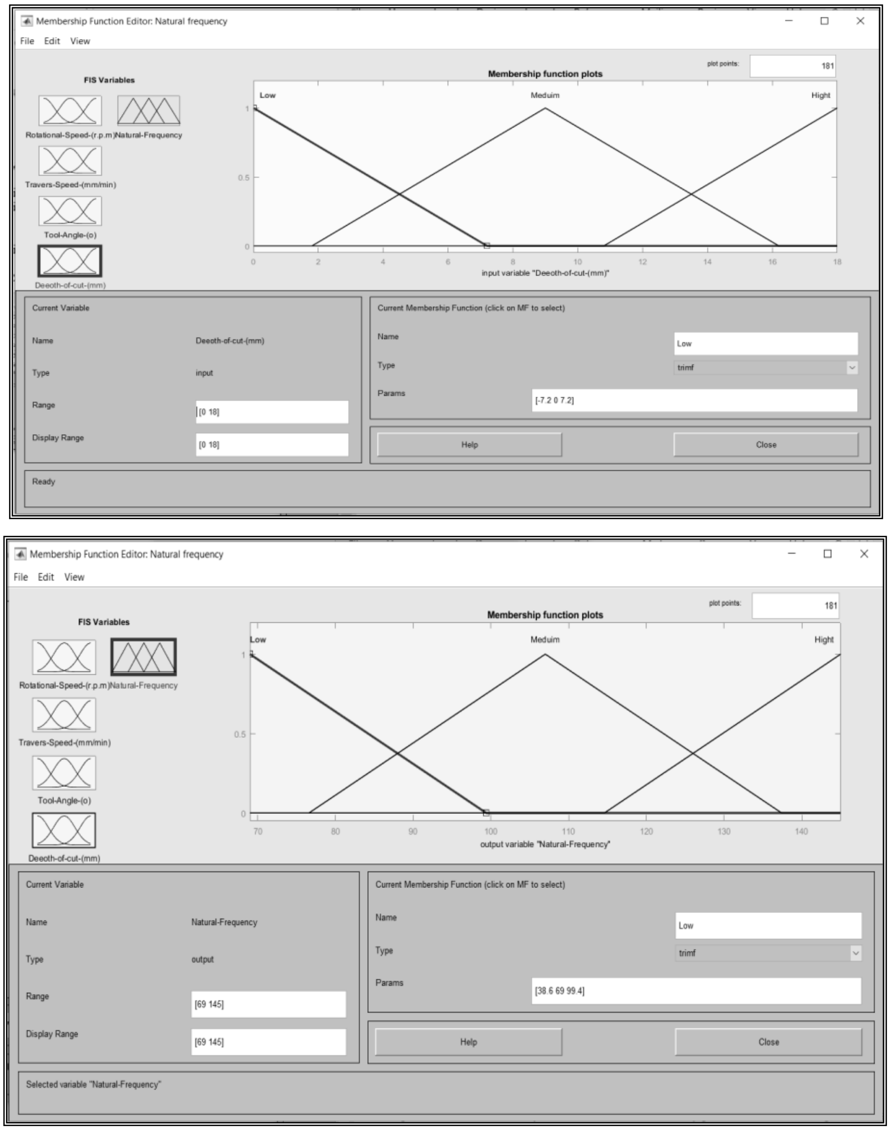

Figure 5. Low, Medium, and High Range of Inputs and Outputs of Natural Frequency Fuzzy System

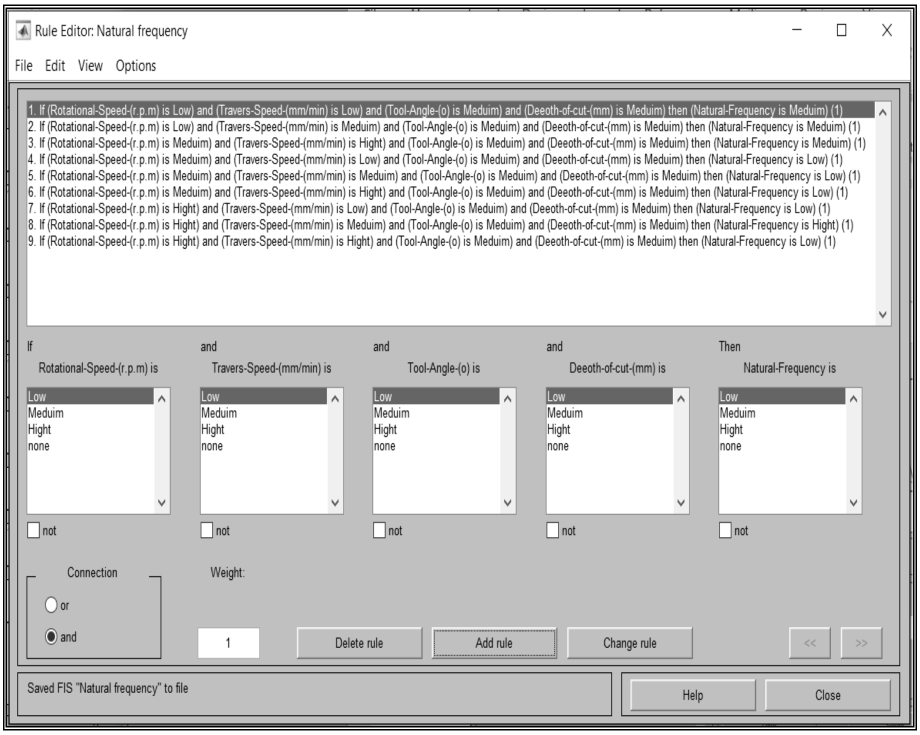

Figure 6: If-Than Rules of Natural Frequency Fuzzy System.

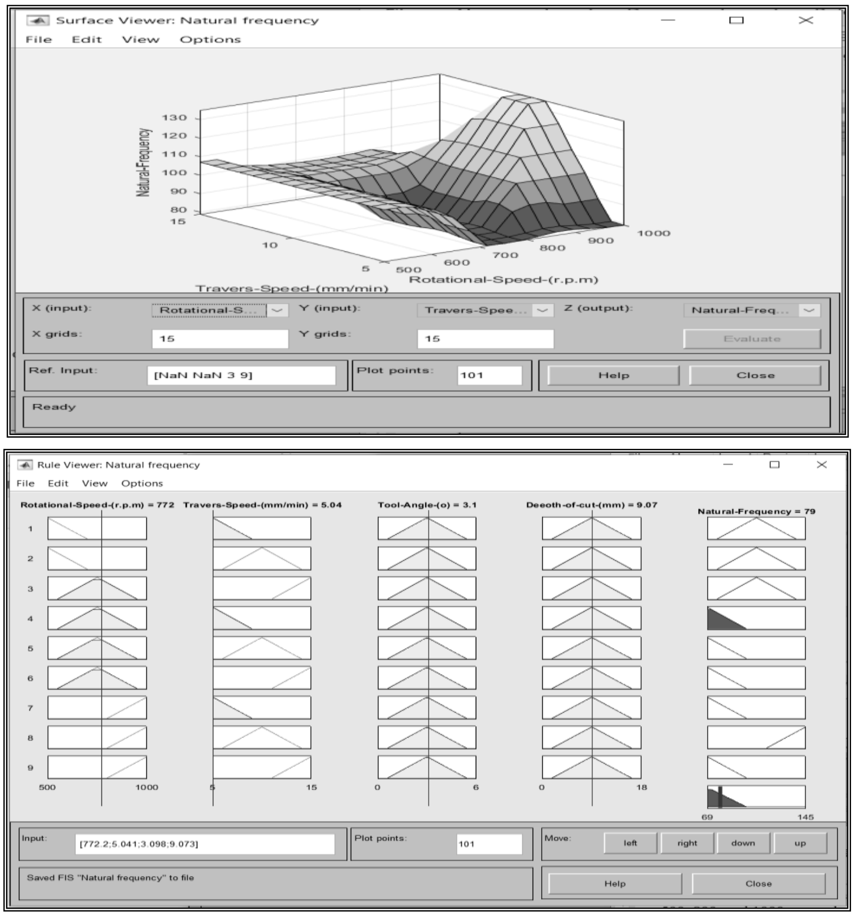

Figure 7: Maximum and Minimum Values of Natural Frequency

Table 3: Maximum and Minimum values of Natural Frequency

Rotational speed	Travers Speed	Tool Angle	Depth of Cut	Natural frequency
998 r.p.m	9.26 mm/min	2.52^{o}	7.44 mm	135 Hz
772 r.p.m	5.04 mm/min	3.1^{o}	9.07 mm	79 Hz

Damping Ratio Fuzzy System

The same input values, that were used for natural frequency fuzzy system were used to design another fuzzy system for optimization of damping ratio AA6061 aluminum alloy structure, as shown in Figure 8. Figures 9, 10, and 11 show values of inputs and outputs, if-than rules and maximum - minimum values of damping ratio. The conditions of maximum and minimum values of damping ratio are shown in Table 4.

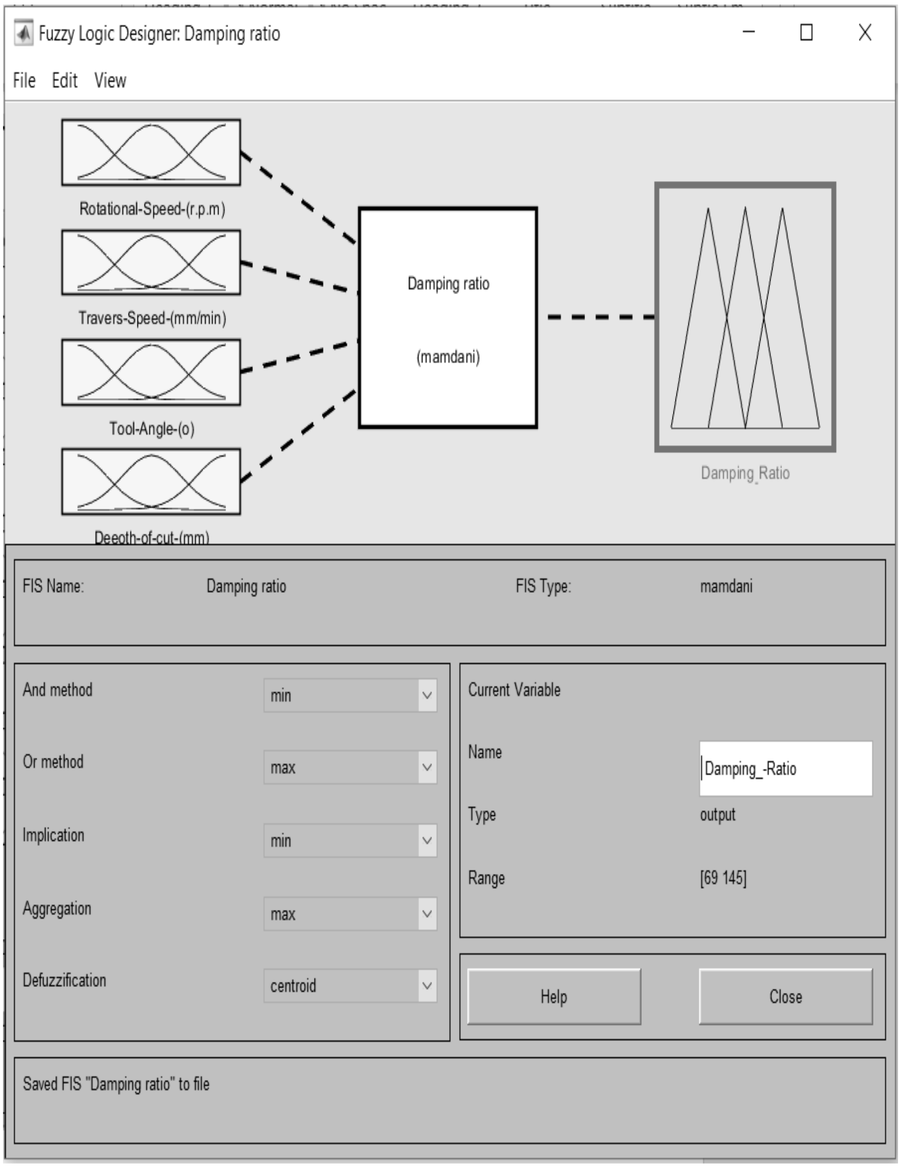

Figure 8: Damping Ratio Fuzzy System.

Figure 9: Output of damping Ratio Fuzzy System.

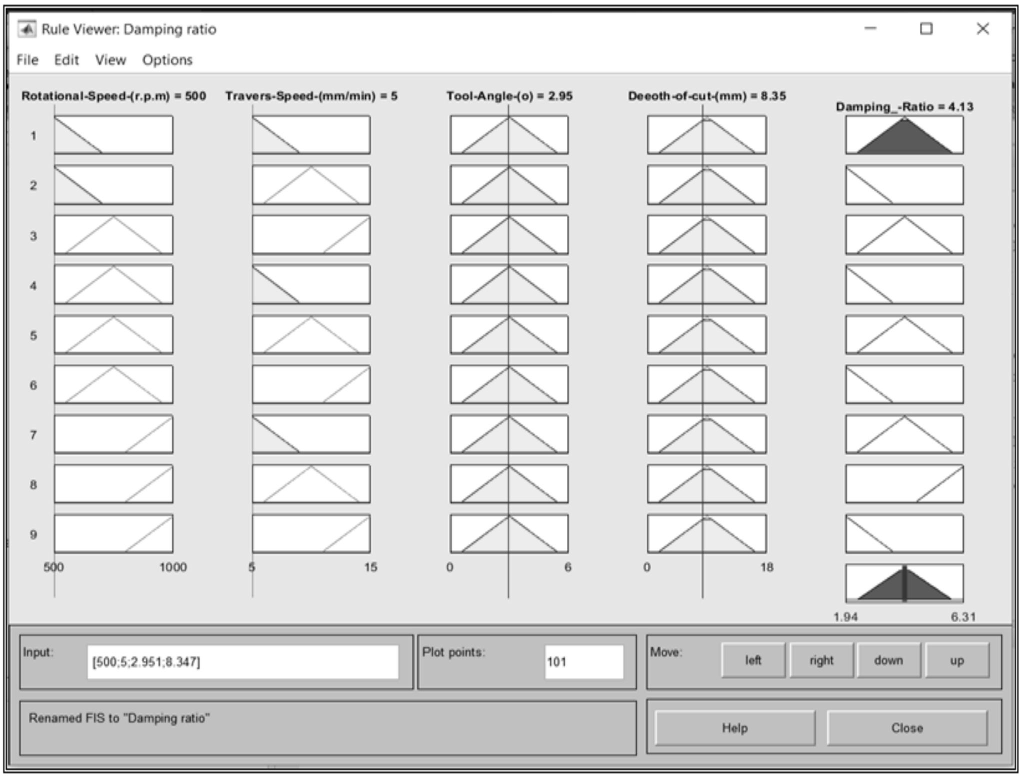

Figure 10: If-Than Rules for damping Ratio Fuzzy System.

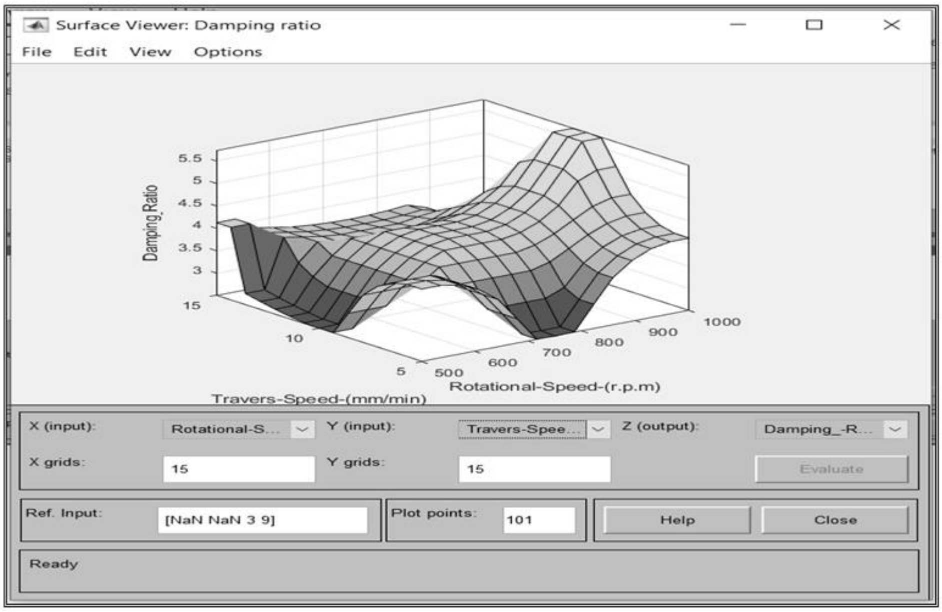

Figure 11: Output Results for Maximum and Minimum values for Damping Ratio.

Table 4: Maximum and Minimum values of Damping Raio

Rotational speed	Travers Speed	Tool Angle	Depth of Cut	Damping Ratio
1000 r.p.m	9.76 mm/min	2.8^{o}	8.35 mm	5.74%
500 r.p.m	9.67 mm/min	2.95^{o}	8.35 mm	2.51%

CONCLUSIONS

In this work, the properties of AA6061 aluminum alloy produced by friction stir welding are investigated. Due to the wide use of this alloy for structures under dynamic loading conditions, the dynamic study of these products has been introduced. A fuzzy logic control system has been implemented to select best conditions of friction stir welding process. The results of applying this fuzzy control to achieve the optimum values for natural frequencies and damping ratio are summarized in Tables 3 and 4.

Several friction stir processing conditions are applied in the experimental study. The spectral analysis of the welded products was used to achieve the optimum values of the dynamic indices using fuzzy control system. The application of the developed fuzzy system indicates that optimum values of the natural frequencies and damping ratio are obtained by increasing rotating and travers speeds at the same values of tool angle and depth of cut.

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Conflicts of Interest: The authors declare no conflict of interest.

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